THE HORIZONTAL REACTIVE MEDIA TREATMENT WELL (HRX WELL®)

DEMONSTRATION OF A NEW TECHNOLOGY FOR PASSIVE IN SITU REMEDIATION

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The HRX Well* is a large-diameter horizontal well installed along the groundwater flow path that is filled with reactive or other treatment media.

- Passive in-situ treatment
- Many solid-phase reactive media options
- Efficient use of reactive media
- Not limited to high-permeability aquifers
- Can be applied in relatively deep settings
- Limited above-ground footprint
- No ongoing energy or O&M requirements
- Pumping can enhance treatment zone

*Arcadis’ Patent US20120261125A1
Calculated Treatment Width

\[ w_{\text{treatment}} = \frac{K_{\text{HRX}} A_{\text{HRX}} i_{\text{HRX}}}{K_A b_A i_A} \]

- \( w_{\text{treatment}} \): HRX Well treatment width
- \( K_{\text{HRX}} \): Hydraulic conductivity of HRX Well
- \( A_{\text{HRX}} \): x-sectional area of HRX Well
- \( i_{\text{HRX}} \): Hydraulic gradient in HRX Well
- \( K_A \): Hydraulic conductivity of aquifer
- \( b_A \): Aquifer thickness
- \( i_A \): Aquifer hydraulic gradient

For passive configurations, treatment widths of tens feet are feasible (even greater with active pumping)
Preliminary Modeling

- 300 ft long, 20 ft deep, 1 ft diameter,
- Homogeneous aquifer, $K_A=2.8$ ft/day, $K_{HRX}=2,800$ ft/day
- Average treatment width = ~40 ft
# Potential Reactive Media and Contaminants

<table>
<thead>
<tr>
<th>REACTIVE MEDIA</th>
<th>CONTAMINANT</th>
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<tbody>
<tr>
<td>Zero Valent iron (ZVI)</td>
<td>Chlorinated solvents (CVOCs), nitrate, perchlorate, energetics, chromium, arsenic, other metals</td>
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<tr>
<td>Bimetallics</td>
<td></td>
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<tr>
<td>GAC</td>
<td>PFAS, CVOCs, hydrocarbons, Halomethanes</td>
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<tr>
<td>Organosilicates (e.g., Osorb®)</td>
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<tr>
<td>Sustained Release Oxidants (e.g., RemOxSR+ISCO)</td>
<td>CVOCs, 1,4-dioxane, hydrocarbons, polyaromatic hydrocarbons (PAHs), phenolic compounds, and energetics</td>
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<tr>
<td>Bioegradable particulate organic carbon (e.g., mulch)</td>
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<tr>
<td>Ion exchange resins</td>
<td>Brines, PFAS</td>
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<tr>
<td>Phosphates (e.g., apatite)</td>
<td>Lead, uranium, other metals and radionuclides</td>
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<tr>
<td>Limestone, lime, magnesium oxide</td>
<td>Low pH, Acid Rock Drainage</td>
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<tr>
<td>Barium sulfate (barite)</td>
<td>Radium</td>
</tr>
<tr>
<td>Iron sulfide</td>
<td>Cr, High pH</td>
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<tr>
<td>Zeolites</td>
<td>Ammonium, radionuclides, PFAS</td>
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</tbody>
</table>
Treatability and Pilot Testing

- No progressive losses in permeability or reactivity over time (>1000 pore volumes)
- Modified laboratory PVP accurately and measured seepage velocities
- Lab and pilot test validated HRX Well hydraulics and numerical model
- Excellent match with actual vs. predicted water levels; HRX Well captured 39% of flow representing 0.5% area
Field Demonstration

- Vandenberg Air Force Base (VAFB)
- Aquifer thickness 7-10 ft
- Depth ~22 ft
- Hydraulic Conductivity: 0.1-0.5 ft/day
- Low hydraulic gradient <0.001
- Groundwater velocity: <0.1 ft/day
- HRX Well installation (8/2018)
Design Model Results

- 56 ft
- 42 ft
Field HRX Well Design

- Length: 550 ft; Depth: 20 ft; Diameter: 12-in;
- Target treatment width: 40-50 ft
- Inlet and outlet Point Velocity Probes (PVPs) to measure in-well flow
- Target residence time: 6-20 days in ZVI (35%, 70 ft), ~100 days total
- Reactive media usage: 0.7 m³ ZVI (1,390 lbs ZVI)
Performance Data - Groundwater Elevations

- Hydraulic gradient increased ~40x near Outlet after HRX Well installation, consistent with model predictions
- Interpreted flow field shows discharge from HRX Well and treatment zone consistent with model predictions

*Data for 3-MW-47 appears to be erroneously low, possibly due to well construction or survey error. However, relative water levels at this well increased after HRX Well installation, consistent with model predictions*
Performance Data – In-Well Flow

- Velocity in media: 8.6 to 10.5 ft/day (+/-9%)
  - Design Model: 7.6 ft/day
- Groundwater velocity in aquifer: <0.1 ft/day
- Equates to flow through HRX Well of 1.7 ft³/d, ~100x ambient flow
- Estimated 9 day ZVI residence time, consistent with design model
Updated Model-Predicted Treatment Zone Widths

Current Passive Operation (HRX Well Flow 1.7 ft³/d)
Performance Data – Contaminant Concentrations

- 99.99% TCE and 97% cDCE concentration reduction from 3-MW-35 to HRX Well Outlet
- Mass discharge reduction ~1.8 g/day
- All downgradient wells indicate treatment with 150 days, consistent with model predictions. TCE concentration reductions: range 29-86%, average 54%
- Temporary reducing conditions due to residual biopolymer drilling fluid likely promoting biotransformation of TCE to cDCE
  - Day 210: Total Organic Carbon 393 mg/L at HRX Well Inlet and 23 mg/L at Outlet. ~87% of treatment by biologically-mediated reductive dechlorination and ~13% abiotic (ZVI)
## Alternatives Analysis

<table>
<thead>
<tr>
<th>Criterion</th>
<th>Alternative #1 HRX Well</th>
<th>Alternative #2 Groundwater Extraction and Treatment System</th>
<th>Alternative #3 Funnel and Gate PRB</th>
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</thead>
<tbody>
<tr>
<td>Overall protection of human health and environment</td>
<td>Yes</td>
<td>Yes</td>
<td>Yes</td>
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<tr>
<td>Effectiveness and permanence</td>
<td>Moderate to High</td>
<td>Moderate</td>
<td>Moderate to High</td>
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<tr>
<td>Reductions in toxicity, mobility, and volume through treatment</td>
<td>Moderate to High</td>
<td>Moderate</td>
<td>Moderate to High</td>
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<tr>
<td>Implementability</td>
<td>Moderate</td>
<td>Moderate</td>
<td>Moderate</td>
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<tr>
<td>Sustainability</td>
<td>High</td>
<td>Low to Moderate</td>
<td>Moderate to High</td>
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<tr>
<td>Lifecycle Cost*</td>
<td>Low to Moderate</td>
<td>High</td>
<td>Moderate</td>
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<tr>
<td></td>
<td>$2.6-3.4M</td>
<td>$3.8-4.7M</td>
<td>$3.6-4.5M</td>
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*Full-scale costs assume a target treatment width of 150 ft, requiring three HRX Wells
Key Takeaways

- Ideally suited for in situ mass flux control
- Efficient media usage and many treatment media options - applicable to many contaminants
- Limited footprint and no ongoing energy, water, or O&M requirements
- Favorable lifecycle cost comparison to P&T and PRB
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